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REVIEW OF THE LATEST TECHNOLOGY IN CARTOGRAPHIC DATA ACQUISITION, MANIPULATION, STORAGE AND PRESENTATION, WITH SPECIAL EMPHASIS ON POTENTIAL APPLICATIONS IN DEVELOPING COUNTRIES: HYDROGRAPHIC SURVEYING AND NAUTICAL CHARTING

Office of Coast Survey: chart production modernization

Paper submitted by the United States of America**

Summary

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** Prepared by Captain Nicholas A. Prahl and Douglas L. Brown, National Ocean Service and National Oceanic and Atmospheric Administration.

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INTRODUCTION

NOAA's Office of Coast Survey (CS) is responsible for providing the Nation a national suite of nautical charts and Coast Pilots, and a comprehensive suite of oceanographic observations and predictions. This national folio of 1,000 nautical charts and nine Coast Pilots and the tide and current observations and predictions for the major ports and estuaries of the United States underpins a suite of marine navigation services which sustains and enhances the Nation's economy; protects life, property, and the environment; promotes commercial and recreational use of the Nation's waterways; and maintains National Security.

For almost three decades, automation has affected how CS carries out the activities that provide these navigation services - both in data collection and product preparation. But, these automated techniques have served primarily to improve the throughput for techniques and processes which represent more than a century of experience and tradition. Fundamental paradigms were not changing. Now, as the program approaches the end of the 20th century, computer and communication technologies have become so pervasive, cost effective, and powerful, these old paradigms are about to be discarded. This paper discusses how the Coast Survey is modernizing its "nautical chart" production activity and how this modernization is challenging the established ways of "doing business" - challenges which will lead to a suite of comprehensive and integrated navigation services.

REQUIREMENTS FOR PRODUCTS

There is little doubt of the strong support for continuing to make nautical charts available in paper form to serve the traditional user. Such users purchase just under a million and a half paper charts per year from NOS. However, the requirement to produce digital data sets to support new and emerging digital marine navigation technologies has been recognized for many years nationally and internationally through such organizations as the International Maritime Organization (IMO), the Safety Of Life At Sea Convention, the International Hydrographic Organization (IHO), and the Radio Technical Commission for Maritime Services. The U.S. National Research Council's Marine Board concluded that the requirement for electronic chart data products is real and that CS must rapidly build and maintain a digital database that more efficiently generates traditional products but more importantly provides the digital data for the commercial deployment of a range of electronic

nautical chart navigation systems (Marine Board 1994). Domestically the USCG has been involved heavily in preparing for the adoption of regulations for carriage of digital nautical charts.

The range of potential digital data sets recognizes a variety of formats and content. The simplest digital chart is a raster image which can be displayed on a screen and georeferenced and overlaid with real-time navigation. The most complex and possibly powerful nautical chart digital data sets are the vector collection of nautical chart features or themes and their databased attributes so that sophisticated manipulation of these data sets can be accomplished by Electronic Chart Display and Information Systems (ECDIS). The IHO and IMO have been establishing standards and formats for such systems and data sets for several years. Unfortunately, no national hydrographic office has had success in the routine production of full vector data sets and many of them have selected the simple raster image as a more reasonable starting point to enter into the digital era.

Clearly, CS has requirements to maintain the paper nautical chart product and to develop and routinely deliver a range of digital chart data products in formats accepted by the international hydrographic community. Given these requirements, CS has a vision that by the year 2005 merchant ships, naval vessels, fishing vessels, and recreational boats will safely ply the Nation's coastal waters, electronically guided by space-based navigation and advanced digital information technologies. CS will be contributing to this revolution in U.S. marine navigation through the modernization of its nautical surveying, data management, and product generation and delivery functions. This vital support will improve the safety and efficiency of marine navigation as the nation witnesses a continual increase in vessels transits and cargo tonnage handled in U.S. ports and harbors.

MODERNIZATION ISSUES

The Office of Coast Survey and its predecessor organizations has undertaken a number of automation/modernization efforts over the last 30 years. The first effort in the mid 1960's took advantage of the minicomputer revolution initiated by Digital Equipment Corporation. This effort saw the automation of major components of the field hydrographic survey system and procedures. This HYDROPLOT-HYDROLOG system was in use with several running modifications until 1989. Attempts to automate the nautical charting production system began around 1970 with the Automated Information System (AIS) project. Tnis was a major attempt to automate existing nautical chart production procedures with the creation of large vector databases of all chart features. The concept was bold, ambitious, and premature with respect to the evolution of computer technology. The project ran for almost 15 years and resulted by 1985 in a procedure for the computer assisted "drafting" of approximately 100 charts out of the suite of one thousand. The system and project were terminated in 1988 because it could no longer be supported internally or externally.

In the mid 1980's specifications and a statement of work was developed for an Automated Nautical Charting System II (ANCS II) which was awarded to the Intergraph Corporation in September of 1988. Again this was a bold, ambitious, and conceptually elegant design which had as its centerpiece

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a vector data base of all chart features for CS' entire area of charting responsibility. The system was delivered in 1995, seven years after the project started.

In 1993, a modest effort began, supported by a NOAA-wide data capture initiative, to create raster images of the entire suite of nautical charts to be available as data sets for low-end electronic charting systems and for coastal managers and planners. This effort and the continuing development of electronic charting standards in the international hydrographic community lead CS in 1995 to prepare a modernization strategy and plan. The following objectives were identified for modernization of chart production:

1. Generate the required products - both paper and electronic.
2. Eliminate the problem of data perishability (Is the chart up-to-date?)
3. Improve product quality and utility, process efficiency, timeliness, and recognize and address any constraining paradigms
4. Replace dated source material - hydrography, topography, etc.
5. Focus on the primary customer - the commercial maritime community.

Each of these objectives is addressed below.

The need for paper and digital versions of nautical charts is well documented, with demand for each version unlikely to shift significantly in the near future. Nevertheless, there is an ongoing transition in CS and other hydrographic authorities away from a product-based orientation and toward the maintenance of a certified national database to support the generation of approved products by private partners who, in turn, make a profit delivering them to the end user. This transition represents a major change in Coast Survey's role in serving the marine navigation community.

The issue of data perishability is central and critical to the provision of a National nautical charting service. The consequence of 25 years of base erosion of program resources has caused, in recent years, a dramatic cut back in the number of new chart editions issued each year. To maintain the currency of the traditional paper chart suite for U.S. waters, nearly 400 new editions should be issued each year to deal with the accumulation of critical changes. During the past two years, personnel and financial resources have limited the number of annual new editions to between 200 and 250. The goal of the program is to keep all one thousand charts continuously up-to-date within a week of the receipt of all source data so that, in practice, a new edition of any chart could be available in real-time. This goal is one of the central objectives of the modernization plan.

Improvement of the product, process efficiency, and timeliness are also central to modernizing. The present paper chart still responds to a number of conditions, requirements, and technologies that existed more than a century ago. The nautical chart still attempts to satisfy a number of different users - the "one size fits all" paradigm. Automation and modernization should change this paradigm allowing for the potential of a variety of digital and graphic products to serve different users. The large cargo vessel steaming north in Chesapeake Bay does not care about much of the cluttered detail depicted near shore on a chart - - he needs basic information about the channel boundaries, depths

and aids-to-navigation. His requirements are different from the recreational boater. In addition, modernizing must also avoid creating redundant parallel production flows or prototype production systems which cannot be easily integrated. The various chart production procedures must be done one time only creating opportunities for what can be referred to as "two for one" or "three for one." This means that a particular production process creates by-products which in and of themselves have great value. This concept will be described more fully under the raster editing/compilation process, below.

The last two objectives listed above emphasize how CS modernization must also address the other consequences of 25 years of resource erosion and loss of field capability. This base erosion has seen the nautical charting survey fleet reduced from its zenith in 1970 of 11 major survey ships to just three in 1997, the elimination of a distributed presence in every major port in the Nation, and the reduction, as noted above, of new nautical chart editions from approximately 500/year in the late 1960's to 200/year in FY 1995. To deal with the diminishing resource base, a decision was made in 1995 to set priorities for the production of those charts which serve primarily the Nation's commercial navigation requirements in its most active ports and harbors. The concept was to reduce the overall demand on program resources so that at least the most important user would be served properly. The ranking of ports is based on a combination of total weight and value of cargo moving through these ports and harbors. Of the suite of nearly 1,000 nautical charts, approximately 200 charts which support navigation in these high priority areas will see frequent new editions of charts on regular cycles which will assure that excessive critical change does not accumulate while the other 800 charts will be produced much less frequently.

With regard to more general upgrading of the information on the nautical chart other than the critical change described above, CS is taking several steps to acquire more current data in digital form. Finally, in Budget year 1996, support from the commercial maritime community resulted in Congressional increases to the program of almost 30%. These increases are being used to contract for new hydrographic and topographic data and to upgrade the nautical charting data base and the tides and ocean circulation prediction services program as well.

THE MODERNIZATION PLAN AND STRATEGY

Coast Survey is committed to have in place by 1999 the suite of nautical charting services described below These services focus on a transition to a condition of continuous maintenance of the data from which products are generated. As noted above, continuous maintenance means that products are current (completely up-to-date) to within a week of receipt of all source data. This level of service is achievable with technology and procedures now in place which form the basis of the modernization plan. The services include but are not limited to:

Maintaining and assuring the distribution of the Nation's suite of nautical charts and nautical charting information in the appropriate formats to serve all classes of waterborne navigation users. With respect to the nautical charts, CS will be responsible for:

a. Continually maintaining digital raster chart composites of the entire suite of more than 1,000 nautical charts so that a new edition of each chart can be produced as often as weekly. The currency of these raster files will support emerging print technologies such as print on demand as well as CD-ROM technologies for distributing digital raster charts.

b. Continually maintaining digital vector chart data in the International exchange format S-57 Edition 3 to support Electronic Chart Display and Information Systems (ECDIS) so that a limited number of critical navigational themes are current to within a week of the receipt of source.

The general strategy to achieve these services involves taking advantage of automation technologies which have, in the past five years, totally changed the way the organization is doing its work. The automated tools to accomplish these goals are no longer large complicated systems but are instead truly off-the-shelf desktop computers, work stations, and software. Productivity gains are almost immediate.

The second part of the strategy is to explore and implement partnerships with private industry through contracts and cooperative agreements while still maintaining strong in-house expertise. These partnerships will provide incentives to the private sector to work with the Government to maintain the critical mix of capabilities to support the Nation's marine navigation service infrastructure.

Diagram 1 depicts the basic functional components of chart production from the receipt of source data to the delivery of products to the customer. The following descriptions explain how the functional areas and components in the diagram are being used or being developed and how they will be integrated over the next two to three years to successfully meet the requirements and vision described above.

Digital Data Sources: Source data for nautical charting comes from nearly 60 source suppliers. The most significant suppliers are the USACE (dredged project survey blue prints) and the USCG (Notices to Mariners). A major effort is underway to develop a more productive relationship with these two primary data suppliers by encouraging them to deliver digital data as opposed to hard copy. Other efforts will focus on proactively seeking source data for chart updating which has not been accessed in the past (e.g.,

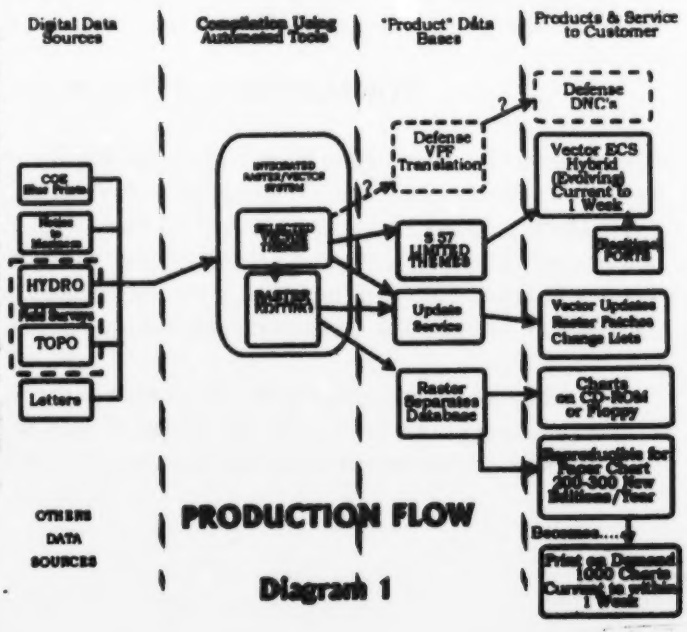

Diagram 1

large scale contract hydrographic surveys of pier faces, etc.). Receiving digital source data is crucial to the modernization of the production processes and the development of the certified nautical charting databases.

Other sources of critical charting data include CS hydrographic surveys and digital shoreline source from the National Geodetic Survey's Photogrammetry Division. In the early 1990's, CS developed a tool to estimate the location and size of the most important (or vital) areas to be surveyed. As with the New Edition priority plan, the focus of this survey prioritization tool is the commercial maritime constituency and risk of major environmental damage associated with a catastrophic grounding. Accordingly, the concept of the "Critical Area" or " Critical Requirements" was developed and they are defined as those areas where the risk of a serious marine disaster exists and where there are high priority commercial user requests for new surveys. Undue risk exists where there is a combination of high traffic volume, inadequate charts or surveys, and potentially insufficient under-keel clearances. Of the 3.4 million square nautical miles (snm) of area CS is responsible for surveying, 43,000 snm have been identified as "Critical".

Part of this survey adequacy analysis includes determining the quality of and currency of the sounding and obstruction data depicted on the charts. Of particular concern is the type of sounding technology used (lead line and single beam sonar vs. modern full bottom multibeam technologies), accumulation of uninvestigated obstructions, and changes caused by migrating shoals. Present survey capacity will complete roughly 1,300 to 1,700 snm annually, but additional requirements have tended to keep the total at a steady state. CS is purchasing state-of-the-art Shallow Water Multibeam equipment to upgrade in-house survey platforms so that the needed full bottom coverage can be accomplished in these critical areas.

Compilation Using Automated Tools: The portion of the diagram depicting "Compilation Using Automated Tools" shows the components of the automated production system now present in CS' Marine Chart Division. This portion of the diagram is the main focus of modernization.

The **Raster Editing/Compilation** component represents the rapid development and deployment of powerful raster editing tools that has allowed the production units to eliminate all manual negative engraving of nautical chart reproducibles in less than 18 months. In addition, the total time from chart compilation to product delivery has been reduced from highs of as much as 35 to 38 weeks to averages of six to eight weeks, and compilation man-hours/chart have been reduced from 200 hours to 140 hours per chart. These raster editing tools are deployed on Pentium PC platforms using a variety of off-the-shelf software including Windows NT, Microstation, and I-RAS B. All 80 cartographers doing compilation work are using these Pentium platforms for raster editing. Where possible, digital source data are brought directly into the editing environment as vector source or as scanned documents. These changes are overlaid, checked, and then "burnt" into the existing raster layer of interest to create New Editions. When digital source material is not available, manual compilation is accomplished on a plastic black line chart drawing. The drawing is scanned and again brought into the raster editing environment. Another significant advantage to this system is the ability of the cartographer to make routine improvements to the chart separate. For example, the

repeated use of the reproducible separates has caused line weights to increase to the point where some soundings and notes are almost illegible. The cartographer can easily replace eligible information on the chart using these raster editing tools.

The raster files generated by these automated tools are used to exclusively supply a private partner under a Cooperative Research and Development Agreement (CRADA) with the digital files for the manufacture and sale of the digital raster nautical charts on CD-ROM and floppy disk. The private partner has successfully completed the entire suite of one thousand charts and has on the market 21 regional CD-ROM chart suites (30 to 70 charts/CD-ROM) as well as individual charts on floppy disk. In addition, these digital raster files are used to generate the reproducibles for the 5-color press to print paper charts. The intention will be to transition from press printing of the charts (in-house or contract) to emerging print-on-demand technologies. This process is a good example of what the program refers to as a "two for one" where the raster files resulting from the editing process serve two needs - the printing requirements as well as the CRADA partner. This digital compilation technique will lead to the continuous maintenance of the entire suite of 1,000 charts so all charts in the suite will be current to within one week.

Continual Maintenance/Update Service. The data base of high resolution raster separates for the suite of one thousand nautical charts along with the highly efficient raster editing tools gives the program the ability to address one of the most critical objectives of modernization - the ability to keep all charts continuously up-to-date. The perishability of the information on a nautical chart is a major concern to the mariner. Have the aids to navigation been altered? Are there new uncharted obstructions? In the recent past, resource constraints have limited the number of new editions of nautical charts that could be issued each year. Unapplied critical change was accumulating against charts in use so that some charts required hundreds of manual Notice-to-Mariners corrections by the user to bring them up to date. A true marine navigation service with regard to charting was not being provided.

The raster compilation/editing environment along with the rapid move toward digital source data is moving each production unit toward the situation where they can keep each set of raster chart separates up-to-date with the source data as it arrives. This capability is referred to as the condition of "continual maintenance".

The movement toward continual maintenance will be lead by the establishment of a weekly chart update service. This service will give the mariner direct access to a certified data base which will contain all Notice-to-Mariners (updated from NIMA and Local, Notices) which will always be current with the publication of the NIMA weekly Notice to Mariners. The service is expected to be available electronically through several potential mechanisms including a private partner and the Internet . The update products will consist of chart specific Notice-to-Mariner change listings and raster patches. A differencing technique will be used to compare the previous week's set of raster separates for a particular chart to the newest set. The difference between the two sets of files results

in an update raster patch which can be used digitally to update a chart file or can generate a graphic patch for use with a paper chart. Again, the update service is a "by product" of the raster compilation process and can be directly accessible through a variety of electronic gateways.

Vector Electronic Chart Data - The Selected Themes Approach. As mentioned above under Requirements for Products, CS recognizes the value of vector digital data. However, creating the vector database of all charted features from high accuracy source material, and creating the various translators to convert from native system formats to the international exchange format for ENCs are extremely expensive and technically difficult problems. CS and many other hydrographic offices around the world have attempted to gather exhaustively (all features) to create standards compliant electronic nautical chart data with extremely limited success.

Realizing the value of some vector information for electronic charting, Coast Survey has reevaluated the concept of exhaustive collection and adopted an incremental strategy which seems to make the most sense technically and operationally from the point of view of the marine navigation community. This approach is illustrated clearly in Diagram 2 which shows that collecting a limited number of navigationally significant themes in vector form is a reasonable starting point in terms of cost and value to the mariner.

Given this reevaluation, Coast Survey has committed to the collection of a reduced set of navigationally significant themes which were determined through a questionnaire to the commercial marine navigation community. The concept is strongly endorsed by pilots and commercial ship operators for being particularly beneficial for collision and grounding avoidance in the close quarters harbor and port navigation environment. The reduced or limited themes data set would be compliant with the international exchange standard (S-57) except for its reduced content. The initial set of 10 themes includes:

- Aids to Navigation
- Bridges
- Anchorages
- Obstructions
- Wrecks
- Rocks
- Cables
- Traffic Separation Schemes
- Pipelines
- Platforms
- Cautionary Areas
- Dredged Areas

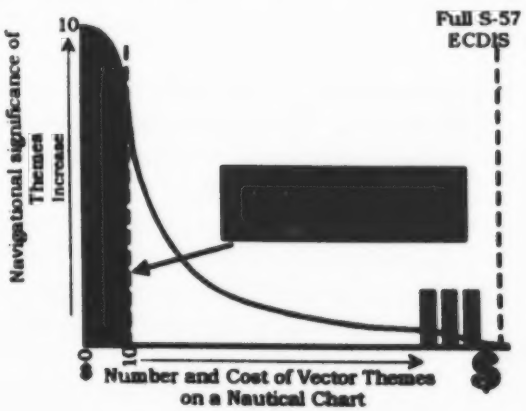

DIAGRAM 2

The concept realizes that other themes such as shoreline and other near shore information which are not included are of value, but the mariner can "marry" the digital raster chart with these selected vector themes by digital overlay, side by side display, or a separate window.

Other critical characteristics of these vector data sets include:

- Very large scale (1:2,500) where possible.
- Collection from high accuracy original source where possible.
- S-57, Edition 3 format.
- Current to within one week at all times.
- Only available as an electronic product and only available electronically.
- Expandable with other large scale data such as 1:2,500 docking charts.
- Updatable with real-time tides and currents.

These characteristics when coupled with Differential Global Positioning System (DGPS) navigation technology provides a powerful navigation tool for the commercial marine navigation community. Diagram 1, above, depicts the selected vector themes production area and how it relates to the raster editing/compilation production flow.

The **"Product" Databases** depicted in Diagram 1 create opportunities for CS to actually move away from the orientation of creating a final product and more toward the development of relationships with chart agents and service providers for the creation of the nautical chart products both digital and paper by the private sector in accordance with standards. Print-on-demand technology is nearly at a point where these types of relationships can be established. The infrastructure for routine transmission of digital data is already here. Although the paper chart will be in use for the foreseeable future even while these new electronic systems and data sets are rapidly evolving and being deployed, the classic printing process is expected to be eliminated in the near term. Users will be able to download and print the latest edition of a chart or the latest raster correction patches and avoid the data perishability issue which results from the old way of doing business.

CONCLUSION

Modernization of the nautical charting data production activity in CS involves two automation efforts -- raster editing / compilation and selected theme vector electronic chart data sets. The raster editing / compilation process is the "engine" that drives CS' chart production program. It was developed rapidly (18 months) in an "ad hoc" fashion with in-house personnel and truly off-the-shelf PC hardware and software. Productivity gains and new product opportunities appeared almost immediately. CS is taking an incremental approach to building a vector electronic chart product, collecting data for the most important themes first. This will provide "intelligent" data which the mariner can use in conjunction with a raster chart display system.

These two automation efforts are giving CS' nautical charting program the capability of meeting in the very near future all modernization objectives and achieving the overall goal of eliminating redundant / parallel production flows.

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